GUIDED WAVES FOR THE INSPECTION OF TITANIUM DIFFUSION BONDS

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INTRODUCTION

The aggressive environment encountered by the high speed civil transport (supersonic) aircraft (HSCT) places severe requirements on the types of materials used in its construction. The state-of- the-art materials available to the commercial aerospace industry will not meet these severe environmental requirements. New materials have been evaluated that will meet these severe environmental requirements. One such material is the super plastic formed/diffusion bonded (SPF/DB) titanium. Structures with this material have been fabricated to be used on the HSCT aircraft. Because the HSCT is a commercial program, the FAA requires that nondestructive evaluation techniques must be developed for the inspection of these structures.

One inspection possibility is ultrasonic guided waves. Currently, successful guided wave techniques have been developed by the authors for inspection of several aging aircraft structures. Extensions of these techniques are presented for application to the inspection of diffusion bonded, titanium structures [1]. Also, a similar analysis is carried out in [2] for the detection of an alpha layer in the titanium diffusion bondline.

METHODOLOGY

Guided wave results are presented on two specimens fabricated by McDonnell Douglas Aerospace with 100% bonding and 10% bonding. Dispersion curves are analyzed for a three layer model of the titanium to titanium diffusion bond system. A multi- mode inspection of two specimens with varying bond quality is subsequently carried out utilizing a frequency sweeping concept. Frequency content and amplitude analysis is carried out, and features are identified for input into a neural network. The neural net is then used to classify the specimens via the ultrasonic data. Directions of further research are identified for future work.

SPECIMENS

The specimens are composed of two layers of a Ti-6AL-4V alloy, each 1mm thick. These individual layers undergo a diffusion bonding process which results in a 2mm flat panel. This panel is then sectioned into a number of rectangular NDE specimens with dimensions of approximately 3.5" x 5". To change the bond quality of the specimens, the diffusion bonding process parameters are varied (Table I). In this case, the quality of the specimens were evaluated via. optical micrographs (Figure 1). The evaluation yielded the results that specimen 1 was completely bonded, while specimen 2 was only 10% bonded.

RESULTS

Dispersion Curve Analysis and 3 Layer Model

A three layer model was developed to analyze the effect of the bondline porosity on guided wave propagation (Figure 2). A .08mm region with degraded properties was included between two .96mm regions with standard titanium properties. The degraded region was chosen to have longitudinal and shear wave velocities of 90% the standard titanium velocities. Subsequently, the guided wave dispersion curves were developed using software that utilizes the partial wave approach. These dispersion curves are then plotted in comparison with the dispersion curves for a solid layer of titanium (Figure 3). It should be noted that the layer thickness and property degradation was chosen arbitrarily, since trends in data were of interest, not quantitative measurements.

Table I. Process parameters for the diffusion bond test specimens.

	Specimen 1	Specimen 2
Temperature (f)	1700	1700
Pressure (psi)	200	(100-120)
Duration (min)	120	2

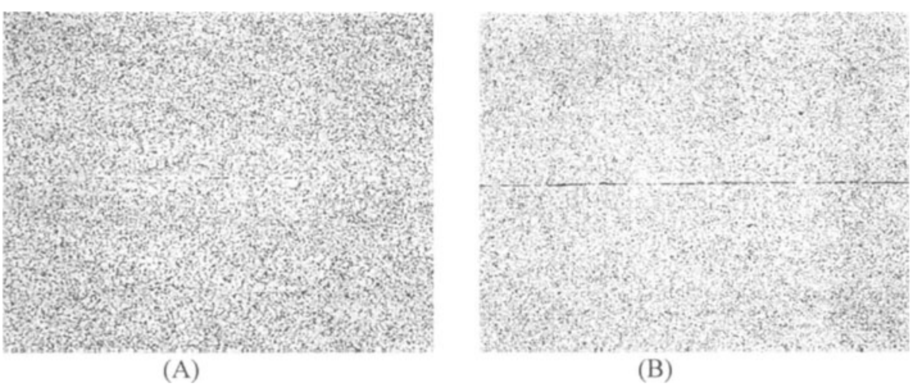

Figure 1. Optical micrographs of the titanium diffusion bond specimens used in this study. A. 100% bonding, and B. 10% bonding.

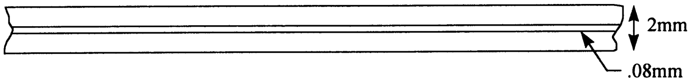

Figure 2. Three layer model used to analyze the effects of bondline degradation.

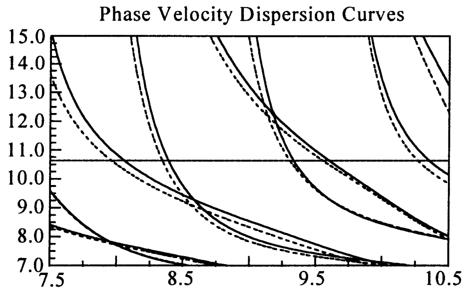

Figure 3. Overlayed dispersion curves for solid layer (solid line) and degraded 3 layer model (dashed line).

The analysis of the 3 layer model shows that there is a mode shift caused by the degraded properties. If the phase velocitiy is held constant and a frequency sweep is performed, the peak resonances should occur at different frequencies for the different specimens if the model was correct. This was performed experimentally on the diffusion bond specimens utilizing a wedge that produced a phase velocity of 10.6 mm/microsec.

Experimental Setup and Results

The experimental setup is shown in figure 4. Longitudinal wave transducers with a center frequency of 10 MHz. were placed on plexi-glass wedges such that a phase velocity of 10.6 mm/microsec. was generated. A tone burst system was used to generate an electrical pulse of 20 cycles at a frequency varying between 7 and 10.8 MHz. The transducers were placed in through transmission and the maximum signal amplitude was plotted as a function of frequency; known as amplitude frequency curves (AFC). Examples of these curves for each specimen are shown in Figure 5.

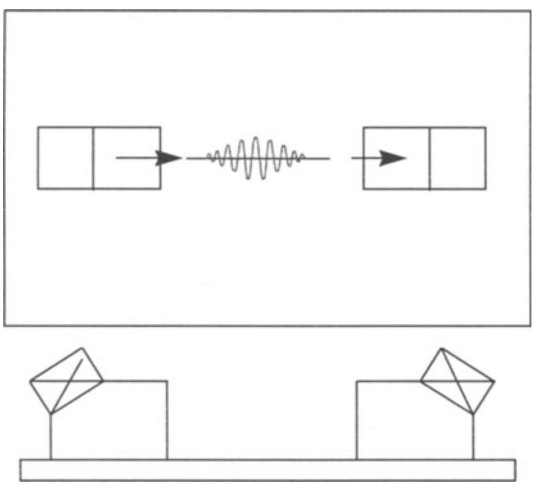

Figure 4. Experimental setup for analyzing the guided wave resonances of the titanium bond specimens.

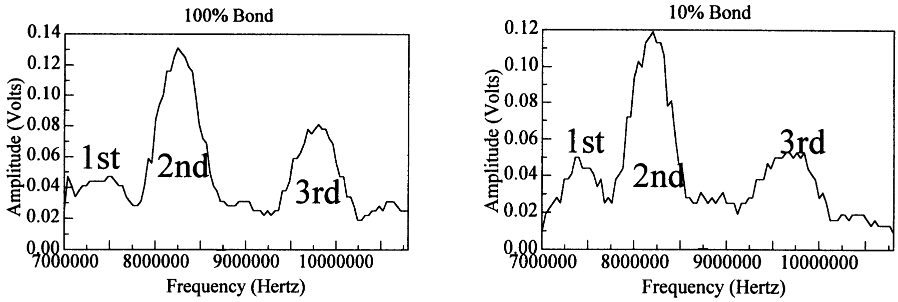

Figure 5. AFC curves for the bond specimens.

Before choosing features from the AFC's, the RF waveforms of the peak resonances were identified on the dispersion curves using a combination of phase and group velocity analysis. It was noted that the overall amplitude of the RF varied greatly due to the ultrasonic couplant, and that amplitude features would not be sufficient in carrying out an inspection. Four features were chosen from a data set of 15 AFC's representing the 100% bonding case and 14 AFC's representing the 10% bonded case. These features were: 1. frequency location of the 2^{nd} peak, 2. frequency location of the 3^{rd} peak, 3. distance in frequency between peaks 2 and 3, and 4. amplitude ratio of peaks 2 and 3.

The value of these features for identifying the specimen was analyzed with probability density functions for the normalized features (Figure 6). Looking at the seperability of the areas of the PDFs, it is concluded that feature 1 and 2 are the best features, feature 3 is possibly useful, and feature 4 is not useful.

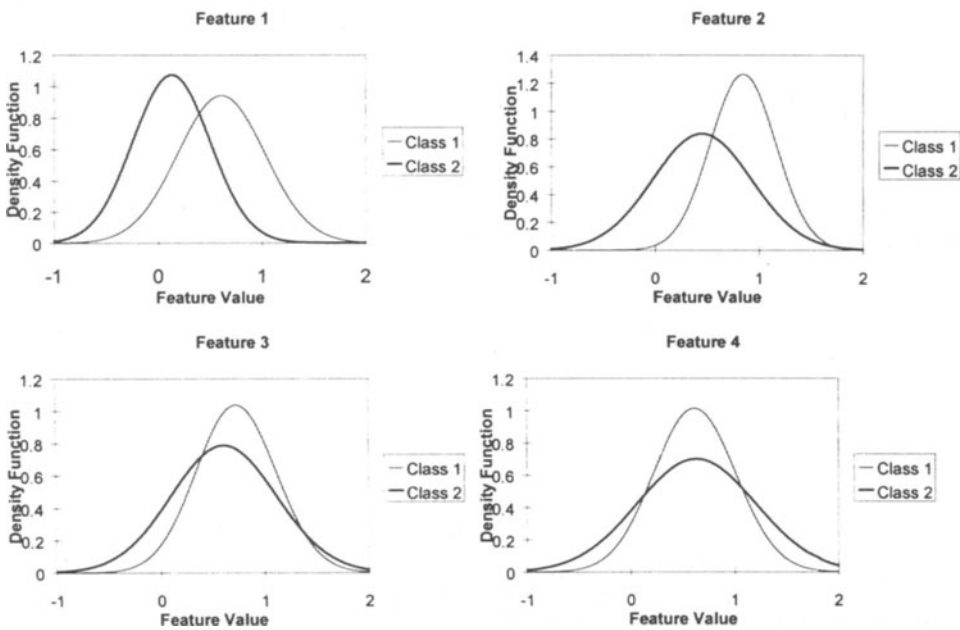

Figure 6. PDF curves for the features chosen from the titanium specimens. Class 1, 100% bond. Class 2, 10% bond.

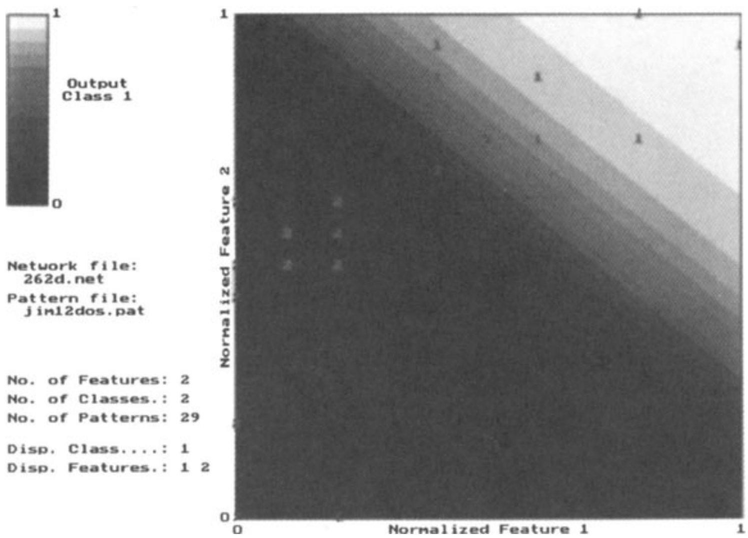

Figure7. Scatter diagram and decision surface for features 1 and 2.

Neural Net Results

Features 1-3 were selected by the PDF analysis to be input to a neural net to attempt to classify the specimens. The neural net correctly classified all but 2 of the 29 data sets, resulting in a classification accuracy of 93.1%. A 2 space scatter diagram was then plotted for features 1 and 2 to analyze the decision boundary. This boundary should be relatively straight between the data sets. If it curved around outlying points, the decision surface would indicate that the neural net was over-trained for that particular data set. The 2 space scatter diagram and decision surface is shown in figure 7.

CONCLUSIONS

The two SPF/DB specimens of varying bond quality easily distinguished using guided waves, indicating feasibility for further research in this direction. Furthermore, amplitude frequency curves in combination with neural net analysis point to a possible inspection technique for the titanium structures. For future study, more specimens with different amounts of debonding will be examined. Also, multi-layered SPF/DB specimens with three or more layers will be studied.

REFERENCES

1. J.L. Rose, K. Rajana, M.K.T Hansch, "Ultrasonic Guided Waves for NDE of Adhesively Bonded Structures," *Journal of Adhesion*, **50**:71-82 (1995).
2. M.J.S. Lowe, P. Cawley, "The Applicability of Plate Wave Techniques for the Inspection of Adhesive and Diffusion Bonded Joints," *Journal of Nondestructive Evaluation,* **13**(4): 185-199 (1994).